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**TECHNICAL NOTE 3127**

## THE EFFECTIVENESS AT HIGH SUBSONIC MACH NUMBERS OF A 20-PERCENT-CHORD PLAIN TRAILING-EDGE FLAP ON THE NACA 65-210 AIRFOIL SECTION

By Louis S. Stivers, Jr.

Ames Aeronautical Laboratory
Moffett Field, Calif.

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## SUMMARY

An analysis has been made of the effectiveness of a 20-percent-chord plain trailing-edge flap on the NACA 65-210 airfoil section from section lift-coefficient data obtained at Mach numbers from 0.30 to 0.875. The analysis also includes a comparison of the effectiveness of this flap with that of a spoiler and a dive-recovery flap on the same airfoil section.

The analysis indicates that the plain trailing-edge flap employed on the 10-percent-thick airfoil section at Mach numbers as high as 0.875 retains at least 50 percent of the effectiveness exhibited at low Mach numbers. The plain trailing-edge flap, as compared to the spoiler and the dive-recovery flap, appears to afford the most favorable characteristics as a device for controlling lift continuously throughout the range of Mach numbers from 0.30 to 0.875. At Mach numbers above those for lift divergence of the airfoil section, either a plain flap or a dive-recovery flap is effective in providing auxiliary lift.

## INTRODUCTION

Among many effects of compressibility which have been found in flight and in the wind tunnel is a reduction in the effectiveness of conventional airplane control surfaces at Mach numbers considerably above the critical for the airfoil. Extremely large reductions in effectiveness accompany the use of the control surfaces on relatively thick airfoil sections at high subsonic Mach numbers. The effectiveness of spoilers and of dive-recovery flaps on 10-percent-thick airfoil sections has been reported in references 1 and 2, respectively. The spoilers became decreasingly effective with increasing projection at high subsonic Mach numbers and exhibited characteristics which were such as to promote erratic lift control for a wide range of Mach numbers. The dive-recovery flaps also showed generally unfavorable characteristics for use, other than emergency, as lift-control devices over an extensive range of subsonic Mach numbers. Wind-tunnel data presented in reference 3 for a plain trailing-edge flap on a modified NACA 65-series airfoil section 19 percent thick indicated

that the effectiveness of a plain flap on this thick airfoil section rapidly decreases as the Mach number is increased above the critical Mach number of the section.

In the present paper, an analysis of the effectiveness of a plain flap on a 10-percent-thick NACA 65-series airfoil section has been made for Mach numbers from 0.30 to 0.875 using data from reference 4. A comparison of the effectiveness of the plain flap, a spoiler, and a dive-recovery flap has also been included.

## NOTATION

| | |
|---|---|
| $c_l$ | section lift coefficient |
| $\Delta c_l$ | increment or decrement in section lift coefficient |
| $\Delta c_d$ | increment in section drag coefficient |
| $\Delta c_{m_{c/4}}$ | increment in section moment coefficient about quarter-chord point |
| M | free-stream Mach number |
| $\alpha_o$ | section angle of attack, deg |
| $\delta_f$ | flap deflection, deg |
| $\frac{\Delta\alpha_o}{\Delta\delta_f}$ | section flap-effectiveness parameter, absolute value of the ratio of equivalent change in section angle of attack to change in flap-deflection angle at a constant section lift coefficient |

## ANALYSIS AND RESULTS

The present analysis of flap effectiveness was made using aerodynamic data obtained in the Ames 1- by 3-1/2-foot high-speed wind tunnel from tests of the NACA 65-210 airfoil section equipped with a 20-percent-chord plain flap. These data, reported in reference 4, were obtained for Mach numbers ranging from 0.30 to approximately 0.90 (with a corresponding range in Reynolds numbers from approximately $1 \times 10^6$ to $2 \times 10^6$) for airfoil angles of attack from $-2^\circ$ to $8^\circ$ and flap deflections from about $-6^\circ$ to $6^\circ$. More precisely, the flap deflections in degrees were found to be -6.3, -4.9, -2.6, 0, 1.9, 4.6, and 6.3. The lift-coefficient data for a Mach number of approximately 0.9 were not obtained at a sufficient number of angles of attack to permit their use in the present analysis. For this reason, only data for Mach numbers as high as 0.875 appear in the figures.

In order to indicate the effectiveness of the plain flap as a lift-producing device, increments of section lift coefficient for each angle of flap deflection have been determined. These increments were obtained throughout the Mach number range at angles of attack corresponding to lift coefficients of 0, 0.2, 0.4, 0.6, and 0.8 at zero flap deflection. Faired curves showing these increments for constant Mach numbers are presented in figure 1 as a function of flap deflection. The same increments for constant flap deflection cross-plotted at each angle of attack given in figure 1 are presented in figure 2 as a function of Mach number.

For some applications it is desirable to evaluate the effectiveness of a lift-control device by some parameter which includes the changes in airfoil section lift-curve slope with deflection of the control. The commonly used flap-effectiveness parameter $\Delta\alpha_o/\Delta\delta_f$, defined as the ratio of the change in section angle of attack to the change in flap deflection necessary to maintain a constant lift coefficient, has been adopted for this use in the present analysis. The variation of this parameter with Mach number for the plain flap of the present report is given in figure 3 for several moderate lift coefficients. For comparison, the variation of the flap-effectiveness parameter with Mach number for a 20-percent-chord plain flap on a 19-percent-thick modified NACA 65-series airfoil section is also shown in figure 3. The curve for the latter airfoil and flap was obtained from figure 43 of reference 3. For the present report, values of $\Delta\alpha_o/\Delta\delta_f$ were taken as the absolute value of the average slopes of the curve of section angle of attack versus flap deflection over a range of flap deflections from $-6^\circ$ to $6^\circ$, for a constant section lift coefficient.

A graph (fig. 4) has been prepared which illustrates the respective variations with Mach number of increments in section lift coefficient with flap deflection for the plain flap and for the dive-recovery flap, and of decrements in section lift coefficient with projection for a spoiler. From the high-speed investigation of a spoiler located at several positions on the upper surface of the NACA 65-210 airfoil section (ref. 1), it appeared that the 50-percent-chord location was the most suitable investigated. Decrements of lift coefficient for various spoiler projections at this location are shown in figure 4 for an angle of attack corresponding to a lift coefficient of 0.2 at zero spoiler projection. Similarly, the increments of lift coefficient for several dive-recovery flap deflections are also shown in figure 4 for a corresponding angle of attack, and for the dive-recovery flap located at the 50-percent-chord position. The high-speed investigation of dive-recovery flaps (ref. 2) indicated that, of three flap locations on the lower surface of the NACA 65-210 airfoil section, the 50-percent-chord position was the most desirable location.

The changes in section drag and pitching-moment coefficients corresponding to the increments (or decrements) of lift coefficient shown in figure 4 are presented in figures 5 and 6, respectively, for the same three lift-control devices.

The dotted portions of certain curves appearing in figures 1 and 2 and of the curve of figure 3 for the 19-percent-thick airfoil section are used to indicate that some uncertainty exists regarding the validity of these data obtained in the vicinity of the wind-tunnel choking Mach number (0.90 at zero angle of attack for the NACA 65-210 airfoil model, and approximately 0.74 at zero angle of attack for the 19-percent-thick airfoil model).

## DISCUSSION

A desirable lift-control device for use on aircraft wings or tail surfaces is one which has uniform effectiveness throughout the range of Mach numbers at which the device is expected to be employed. Furthermore, if an airplane is to maintain controlled flight at Mach numbers above those for lift divergence of the wing, it must be possible to compensate for the lift deficiency of the wing at these Mach numbers. These two particulars are considered in the succeeding discussion both in regard to the plain flap of the present analysis and in regard to the comparison that follows.

### Effectiveness of the Plain Flap as a Lift-Producing Device

The increments of section lift coefficient given in figures 1 and 2, which indicate the effectiveness of the flap as a lift-producing device, show that the effectiveness increases somewhat with an increase in Mach number above 0.30 reaching a maximum at a Mach number apparently depending on the magnitude of the flap deflection and the airfoil angle of attack. The Mach numbers for which the increments of lift coefficient are greatest correspond approximately, in most cases, to the airfoil lift-divergence Mach numbers given in figure 8 of reference 4. As the Mach number is increased above those at which the maximum increments occur, the effectiveness decreases in varying degree. The minimum effectiveness indicated for Mach numbers up to 0.875, however, is never less than 50 percent of that at low Mach numbers. Although the data of figures 1 and 2 indicate appreciable variations in the effectiveness of the plain flap for Mach numbers between 0.30 and 0.875, it is believed that these variations will not too seriously limit the application of this control device on a 10-percent-thick rigid airfoil in the said Mach number range.

In figure 3, it is observed that the flap-effectiveness parameter $\Delta\alpha_o/\Delta\delta_f$ for the plain flap on the NACA 65-210 airfoil section varies appreciably over a range of moderate lift coefficients at high Mach numbers. The only marked decreases in effectiveness, however, appear to begin at Mach numbers near 0.83 for low lift coefficients. The largest decrease in effectiveness, for Mach numbers up to 0.875, is indicated for zero lift coefficient where the effectiveness has reduced to a value which is approximately 50 percent of that shown for the low Mach numbers.

A comparison of the curves of figure 3 for the two airfoil sections employing 20-percent-chord flaps shows that the effectiveness exhibited by the flap on the 19-percent-thick section at high Mach numbers is quite different from that for the 10-percent-thick section. The curve for the 19-percent-thick section shows a marked decrease in the effectiveness of the flap at a Mach number near 0.70 which is approximately 0.13 Mach number less than that corresponding to the abrupt decrease in effectiveness of the flap on the 10-percent-thick section at low lift coefficients.

## Comparison of the Effectiveness of a Spoiler, a Dive-Recovery Flap, and a Plain Flap

The relative merits of a spoiler, a dive-recovery flap, and a plain flap for providing lift control on an airfoil can be evaluated from the lift-coefficient data presented in figure 4. It can be seen readily from the data that the variations with Mach number of the effectiveness of the spoiler and the dive-recovery flap between Mach numbers of 0.30 and 0.875 are considerably larger than the corresponding variations for the plain flap. Because of these large variations in effectiveness for the dive-recovery flap, and especially for the spoiler, an airplane control system employing either of these devices would tend to provide at high subsonic Mach numbers too rapid airplane response to control movements if satisfactory control characteristics were maintained at low Mach numbers. For producing lift continuously throughout a wide range of Mach numbers, the plain trailing-edge flap, accordingly, appears to possess the most favorable characteristics.

It is apparent in figure 4 that each of the lift-control devices is capable of providing auxiliary increments (or decrements) of lift coefficient in the range of Mach numbers between 0.75 and 0.875. These increments, however, vary differently for each lift device with changes in Mach number, and decrease with increase in Mach number at the highest Mach numbers shown, except for the $10^{\circ}$ deflection of the dive-recovery flap and for positive deflections of the plain flap. The plain flap appears to have no particular advantage over the dive-recovery flap for providing positive increments of lift at Mach numbers between 0.75 and 0.875 on a 10-percent-thick airfoil section unless it be at the highest Mach numbers.

The increments of drag coefficient corresponding to constant increments of lift coefficient, as shown in figure 5, are seen to be quite different for the three lift-control devices. The characteristics for the plain flap appear to be the most desirable, since the data indicate that the increments in drag accompanying a given increment in lift are the least for the plain flap at any Mach number from 0.30 to 0.875. Between 0.75 and 0.875 Mach numbers, the increments in drag coefficient for constant increments of lift coefficient of the dive-recovery flap increase very rapidly with increase in Mach number. In the case where a lift-control device is used on an airplane wing as a purely emergency

implement for aid in recovery from high-speed dives, however, a substantial increase in drag, such as noted for the dive-recovery flap, may be desirable in order to limit the diving speed of the airplane.

At constant increments of lift coefficient, the increments of pitching-moment coefficient presented in figure 6 do not vary a great deal with change in Mach number except, for the most part, at the highest Mach numbers. For negative increments of lift at Mach numbers between 0.30 and 0.875, the plain flap and the spoiler exhibit, in general, positive increments of pitching moment which tend to increase at the highest Mach numbers for the larger negative increments of lift. The pitching-moment increments for positive increments of lift are negative for the plain flap and positive for the dive-recovery flap except for the larger increments of lift at high Mach numbers. The data show that the increments of pitching moment are always more positive for the dive-recovery flap than are the corresponding pitching-moment increments for the plain flap. For positive increments of lift in the range of Mach numbers from 0.75 to 0.875, the pitching-moment coefficients for the plain flap are always negative (not in the direction to oppose the diving tendency); whereas for the dive-recovery flap they appear to be either positive or negative, depending on the Mach number and the increment of lift coefficient.

## CONCLUSIONS

The analysis of the lift-control characteristics of a 20-percent-chord plain trailing-edge flap on the NACA 65-210 airfoil section and a comparison of the effectiveness of this device with that of the spoiler and the dive-recovery flap indicate the following:

1. At Mach numbers as high as 0.875, the plain flap on the 10-percent-thick airfoil section retains at least 50 percent of the effectiveness afforded at low Mach numbers.

2. As compared to the spoiler and the dive-recovery flap, the plain trailing-edge flap would appear to afford the most favorable characteristics as a device for controlling lift continuously throughout a range of Mach numbers from 0.30 to 0.875.

3. Either a plain flap or a dive-recovery flap is capable of providing auxiliary lift at Mach numbers above those for lift divergence of the airfoil section.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Jan. 17, 1947

## REFERENCES

1. Velasco, Carlos E.: High-Speed Wind-Tunnel Investigation of Spoilers for Lateral Control on the NACA $65_1$-210 Airfoil Section. NACA MR A5K02, 1945.

2. Olson, Robert N., and Benezra, Joseph N.: High-Speed Wind-Tunnel Investigation of Dive-Recovery Flaps for Lift Control on the NACA 65-210 Airfoil. NACA ARR 6D23, 1946. (Formerly NACA MR A5K14)

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4. Graham, Donald J., and Adams, Charles N., Jr.: Wind-Tunnel Investigation of a 20-Percent-Chord Plain Flap on the NACA $65_1$-210 Airfoil for Lift Control at High Speeds. NACA MR A5F05, 1945.

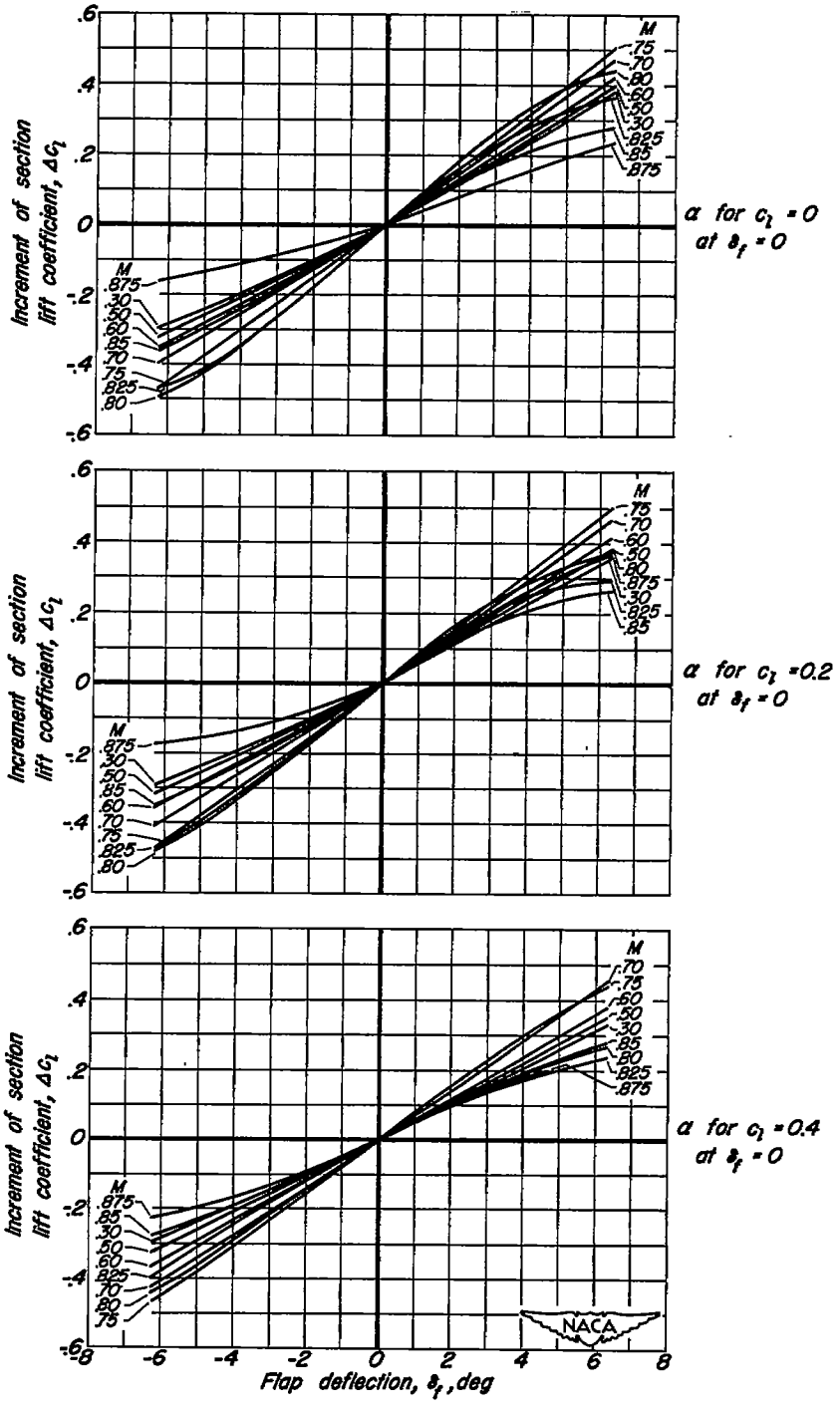


*Figure 1.– Variation of the increment of section lift coefficient with flap deflection at various Mach numbers for several angles of attack of the NACA 65-210 airfoil section with a 0.20–chord flap.*

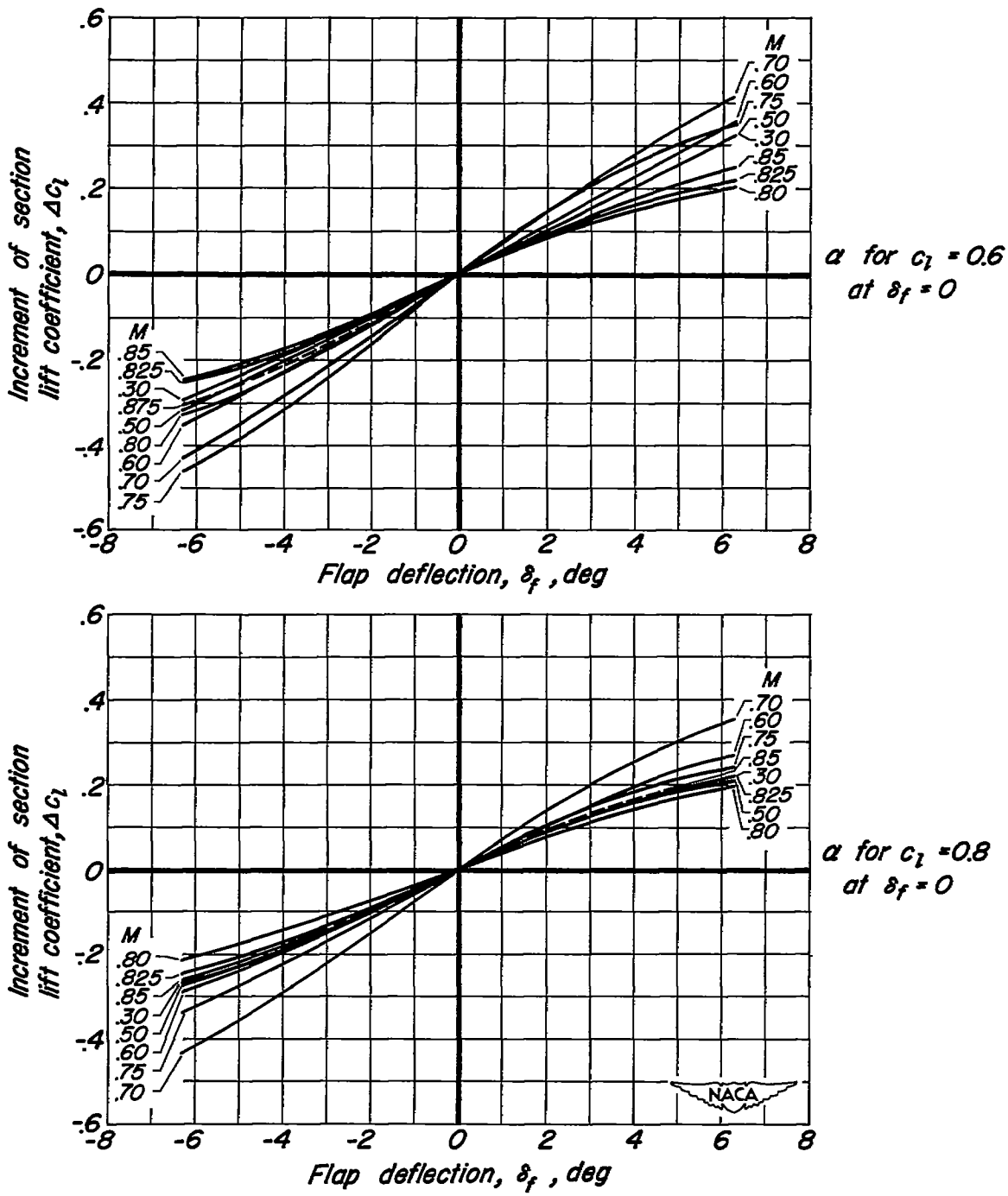


Figure 1.– Concluded.

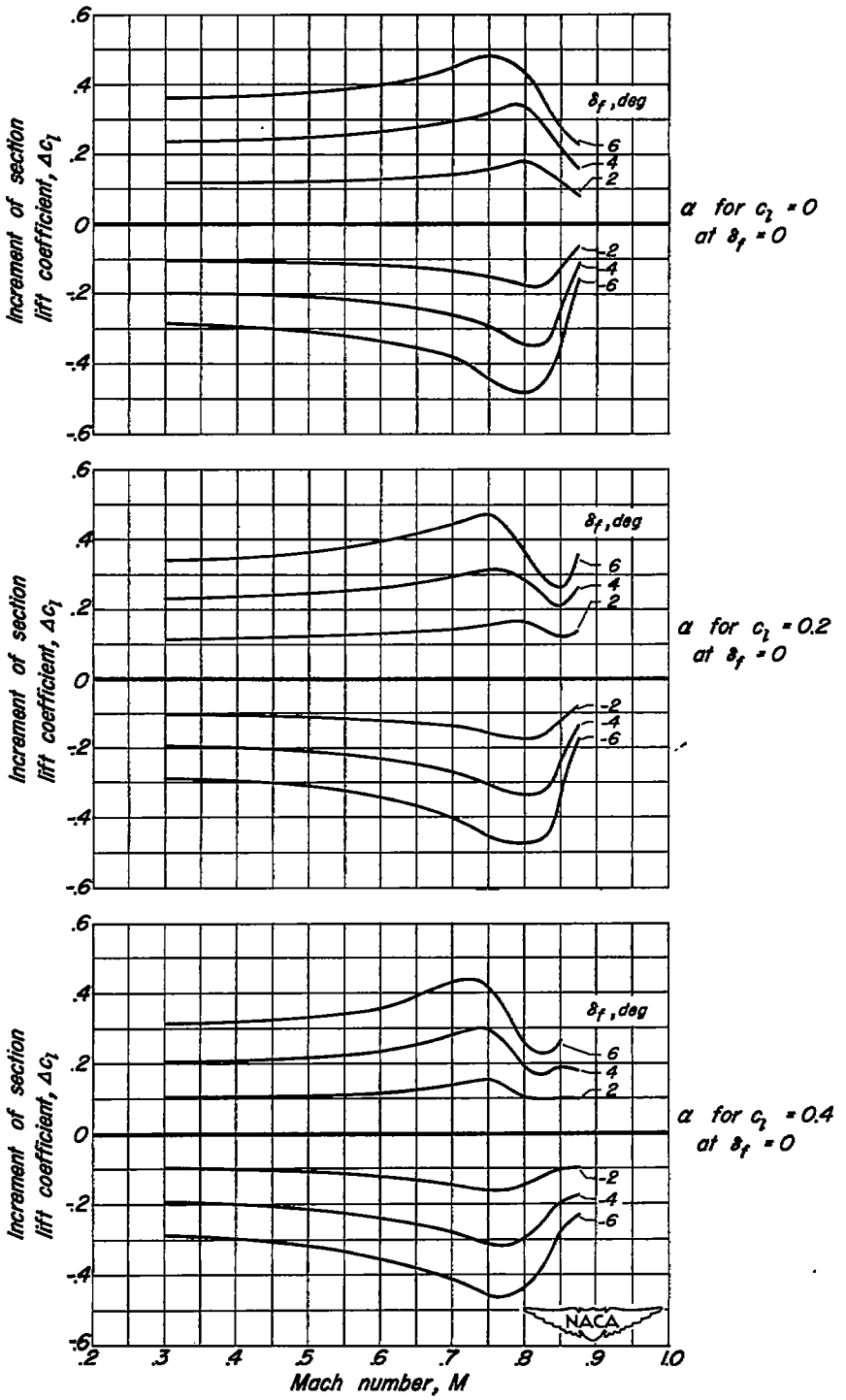


*Figure 2.- Variation of the increment of section lift coefficient with Mach number for various flap deflections and angles of attack of the NACA 65-210 airfoil section with a 0.20-chord plain flap.*

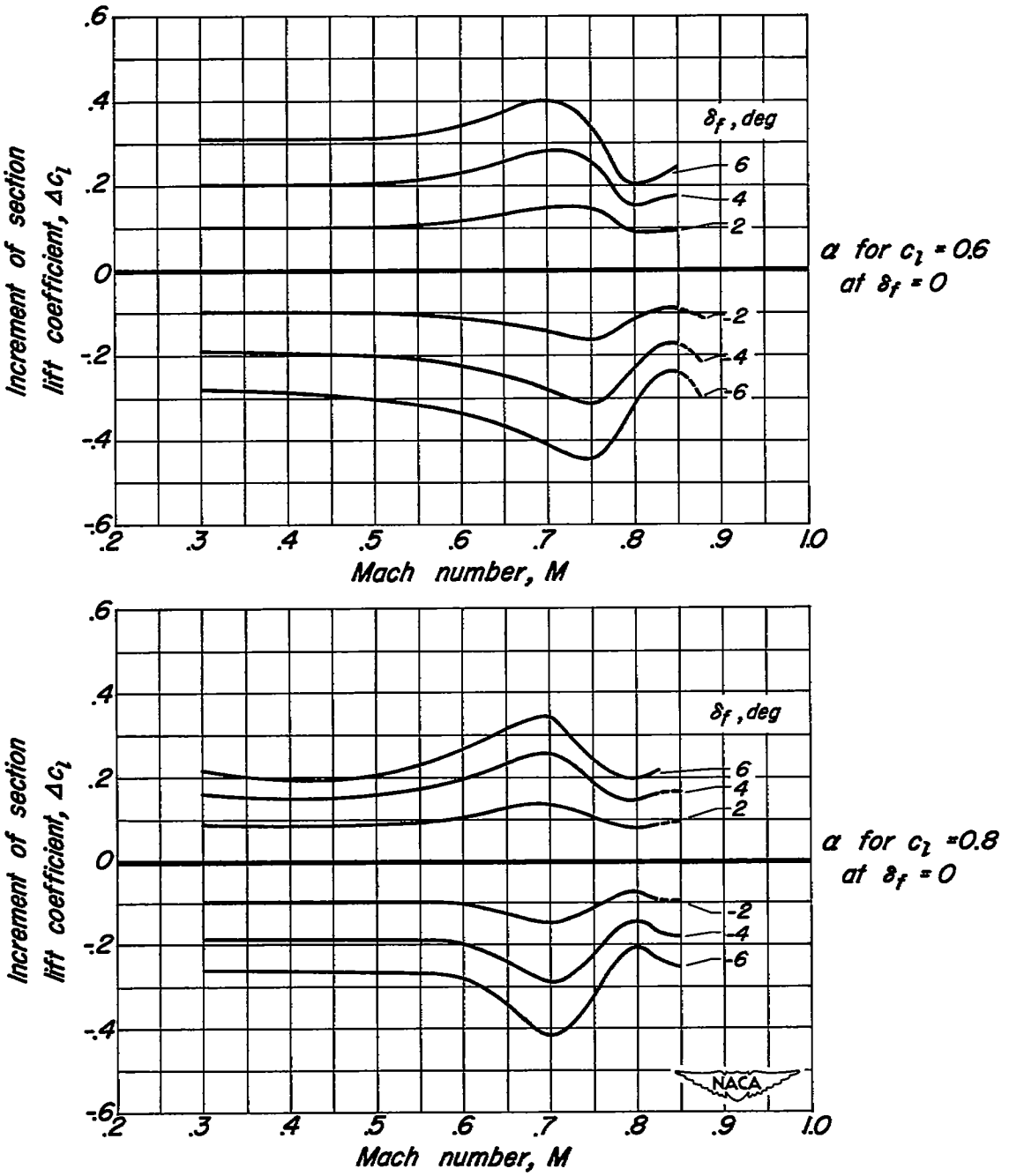


*Figure 2.—Concluded.*

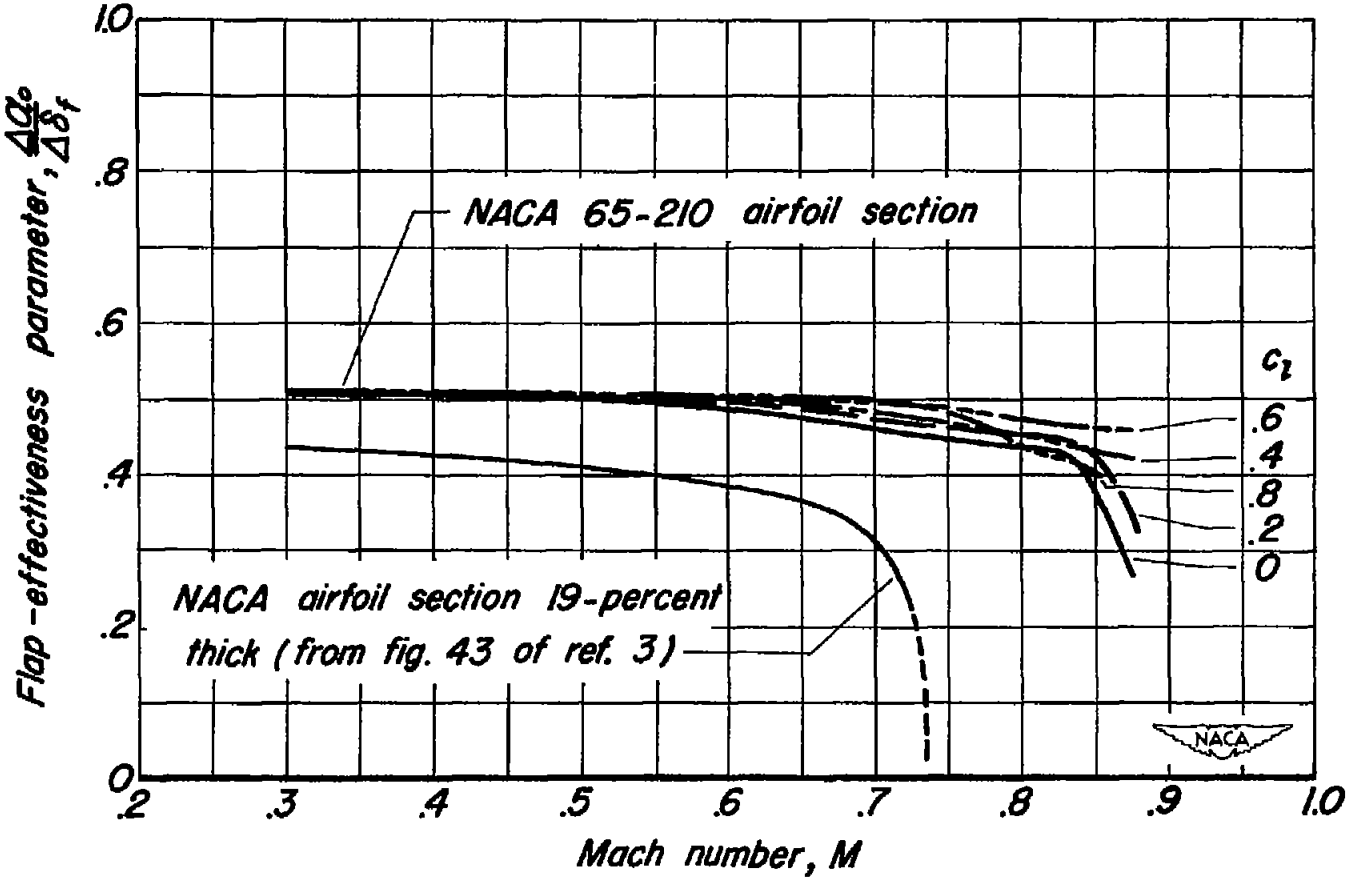


*Figure 3.–Comparison of the flap effectiveness at various Mach numbers for the NACA 65-210 and 19-percent thick 65-series airfoil sections with 20-percent-chord plain flaps.*

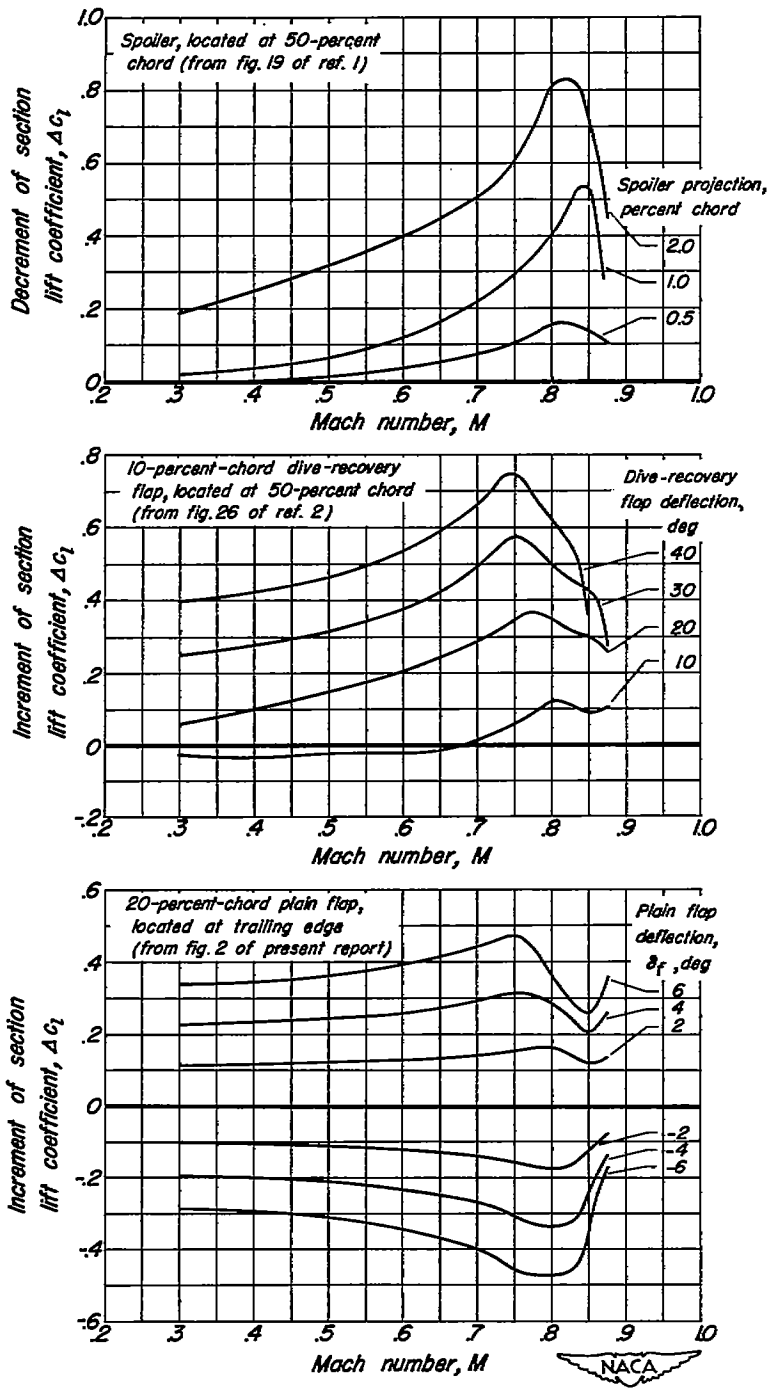


*Figure 4.-Comparison of the lift-control characteristics of a spoiler, a dive-recovery flap, and a plain flap on the NACA 65-210 airfoil section at an angle of attack corresponding to a lift coefficient of 0.2 for zero deflection of the control device.*

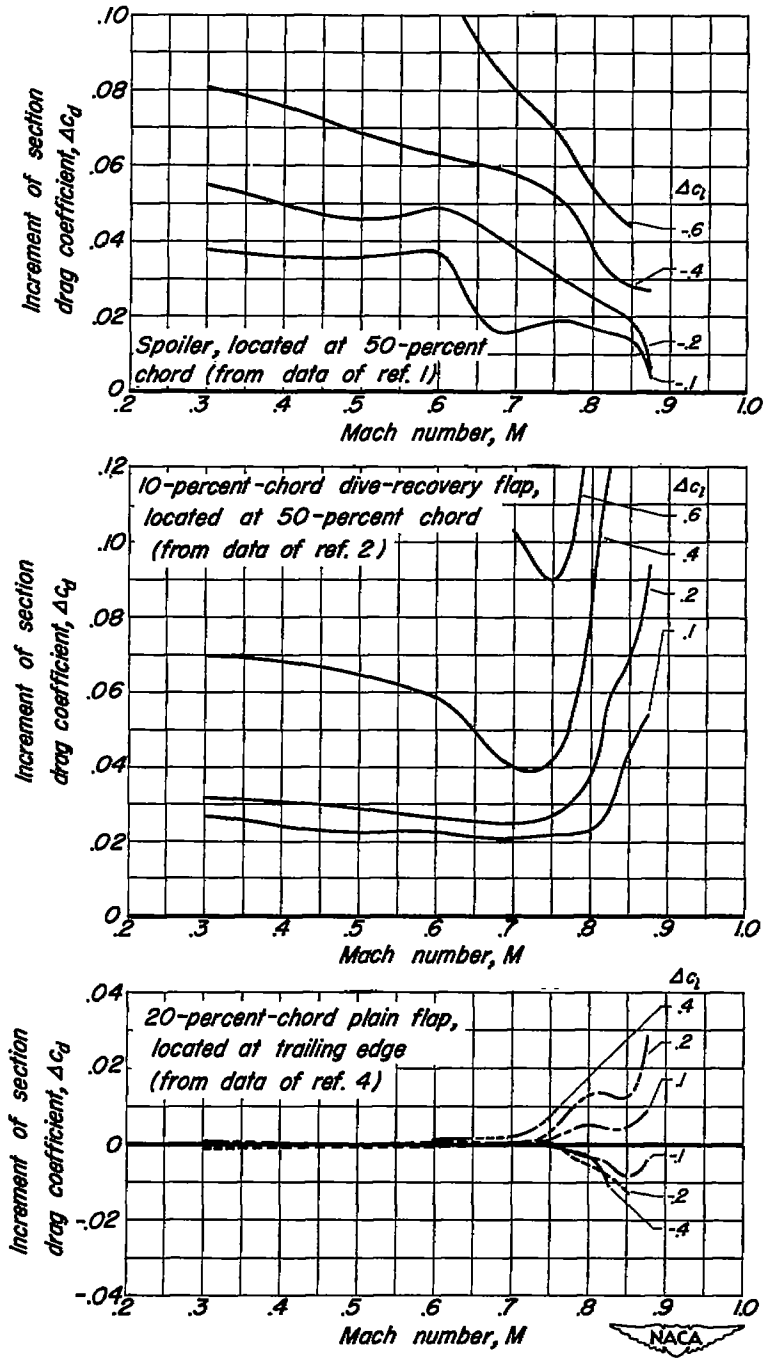


*Figure 5.- Comparison of the increments of section drag coefficient corresponding to constant values of increment in lift coefficient given by a spoiler, a dive-recovery flap, and a plain flap on the NACA 65-210 airfoil section at an angle of attack corresponding to a lift coefficient of 0.2 for zero deflection of the control device.*

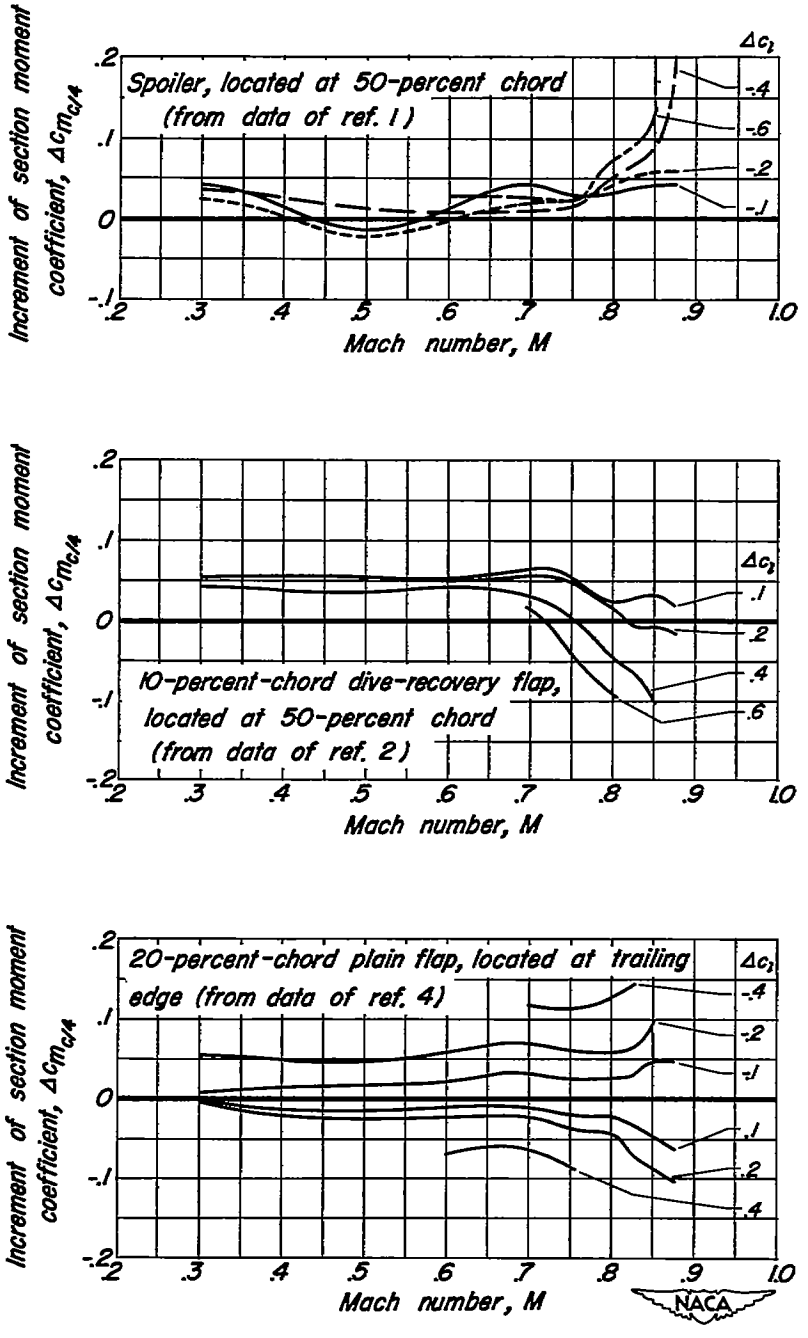
Spoiler, located at 50-percent chord
(from data of ref. 1)
10-percent-chord dive-recovery flap,
located at 50-percent chord
(from data of ref. 2)
20-percent-chord plain flap, located at trailing
edge (from data of ref. 4)
Increment of section moment coefficient, $\Delta c_{m_{c/4}}$
Mach number, M
$\Delta c_l$
NACA

*Figure 6.-Comparison of the increments of section moment coefficient corresponding to constant values of increment in lift coefficient given by a spoiler, a dive-recovery flap, and a plain flap on the NACA 65-210 airfoil section at an angle of attack corresponding to a lift coefficient of 0.2 for zero deflection of the control device.*